

LEVEL III

12



FINAL REPORT

CHEMICAL INITIATION OF FAE CLOUDS

Submitted to:

Department of the Air Force
Office of Scientific Research
Directorate of Aerospace Sciences
Bolling AFB, Washington, D.C. 20332

Attention: Dr. Bernard T. Wolfson

Under Contract No. [REDACTED]

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Submitted by:

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November 1980

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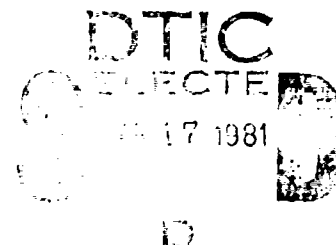
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fuel and CTF has been demonstrated in which the combustion air is entrapped between the jets and entrained and burned as the jets explode. The jets are generated by the combined effects of Taylor instability and indentations in the dispersing explosive charge. The mass flow that is induced by the cloud explosion generates a coherent shock wave. In the present small-scale tests, the flow is strongly divergent and the shock Mach number is only of the order of 3. In a large-scale cylindrical FAE configuration, the shock wave would not be attenuated by flow divergence and the shock Mach number would be expected to be of the order of 4 to 5. In that case, the shock wave is expected to become a detonation wave much like the detonation wave in an FAE cloud with second-event initiation.

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ABSTRACT

A jet-structured FAE cloud of dispersed fuel and CTF has been demonstrated in which the combustion air is entrapped between the jets and entrained and burned as the jets explode. The jets are generated by the combined effects of Taylor instability and indentations in the dispersing explosive charge. The mass flow that is induced by the cloud explosion generates a coherent shock wave. In the present small-scale tests, the flow is strongly divergent and the shock Mach number is only of the order of 3. In a large-scale cylindrical FAE configuration, the shock wave would not be attenuated by flow divergence and the shock Mach number would be expected to be of the order of 4 to 5. In that case, the shock wave is expected to become a detonation wave much like the detonation wave in an FAE cloud with second-event initiation.

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1.0 INTRODUCTION

Research on chemical single-event initiation of FAE clouds is principally directed toward the problem of blast yield. The "single-event" that initiates the FAE blast is the detonation of the central explosive charge, and the blast yield accordingly depends on the subsequent dispersal of fuel and incendiary chemical agent into the ambient air and ensuing release of energy by agent reaction and fuel combustion. Within these constraints one must search for a blast-efficient experimental configuration. Thus, the work at McGill University is directed toward obtaining a period of ignition delay that permits completion of the dispersal process prior to chemical energy release, followed by a timed sequence of energy release throughout the cloud which produces coherent pressure pulses for shock wave amplification to detonation - the SWACER mechanism. The work at Atlantic Research is based on a different concept. It appears that by using the highly reactive agents ClF_3 (CTF) or BrF_3 (BTF) in conjunction with an efficiently dispersing explosive charge, one does not require an ignition delay for premixing fuel and air, inasmuch as in such an arrangement, ignition and fuel dispersion are expected to occur simultaneously at such high rate that an effective blast-generating piston force is maintained throughout the process of cloud generation and combustion. That is, it seems possible in this way to obtain an effective FAE blast by mass flow generated by very rapid dispersion and energy release.

This is confirmed by the work that is described in the present report. It is shown that a large FAE cloud of this type is expected to detonate much like an FAE cloud with second-event initiation.

2.0 REVIEW OF PREVIOUS WORK

The principle of blast generation by rapid dispersal and ignition was originally demonstrated in the laboratory by pneumatically injecting about 0.05 cm^3 BTF into 0.6 cm^3 diesel oil in an open cup. The explosive dispersal of the fuel in these miniature experiments produced well-measurable blast pressures which were considerably larger when the ambient atmosphere was air instead of nitrogen, and very much larger when the ambient atmosphere was oxygen. It was thus demonstrated that the blast wave is reinforced by release of combustion energy in the fuel/oxygen reaction. However, according to the data only a fraction of the available combustion energy was utilized

in the blast generation, and high-speed motion photography showed a period of afterburning of the cloud which did not contribute to the blast. It was concluded that the reinforcement of the blast wave by release of combustion energy depends on the rate of entrainment of air or oxygen behind the receding blast wave, and further that the release of combustion energy is kinetically limited by the finite rate of the fuel/oxygen reaction.

This kinetic limitation does not appear to be significant if one considers a hypothetical scale-up of the experiment from less than one gram of fuel to several hundred pounds. In that case the distances of travel of the receding blast wave for comparable stages of separation from the cloud would be so large and the corresponding travel times would be so long that there should be adequate time for the combustion reaction to reinforce the wave effectively. Further work was thus primarily concerned with the effect of the experimental configuration on the rate of air entrainment. This did not require an extravagant test scale. Thus, field experiments, performed subsequent to the laboratory experiments, have been conducted with less than one pound of fuel. These experiments, referred to as "small scale," have already been described in detail in the previous report. The following is a brief recapitulation of the principal observations and conclusions.

A 4-gram explosive charge was surrounded by 35 cm^3 of CTF or BTF and 350 cm^3 of diesel oil or heptane in an annular configuration that was confined between two 7-inch diameter steel blocks. The arrangement is shown in Figure 1. The growth and luminosity of the resulting annular ("pancake-shaped") FAE clouds were observed by high-speed motion photography, and the blast waves were monitored by pressure sensors at various distances. In this arrangement the energy released by the explosive charge and by the fuel/agent reaction was absorbed by the fuel dispersion and the blast was generated by the fuel/air reaction only. This was shown by the observation that no blast was generated when the test was performed in an atmosphere of nitrogen.

The blast was very strong in an atmosphere of oxygen, but in open air it was less than expected. From a study of the contours of the FAE clouds, Figure 2, in relation to the distance of travel and decay of the blast wave, it was concluded that the blast generation was associated with the deep protrusions and indentations of the cloud surface that were generated in the early stage of cloud formation by the effect of Taylor instability. Thus, the

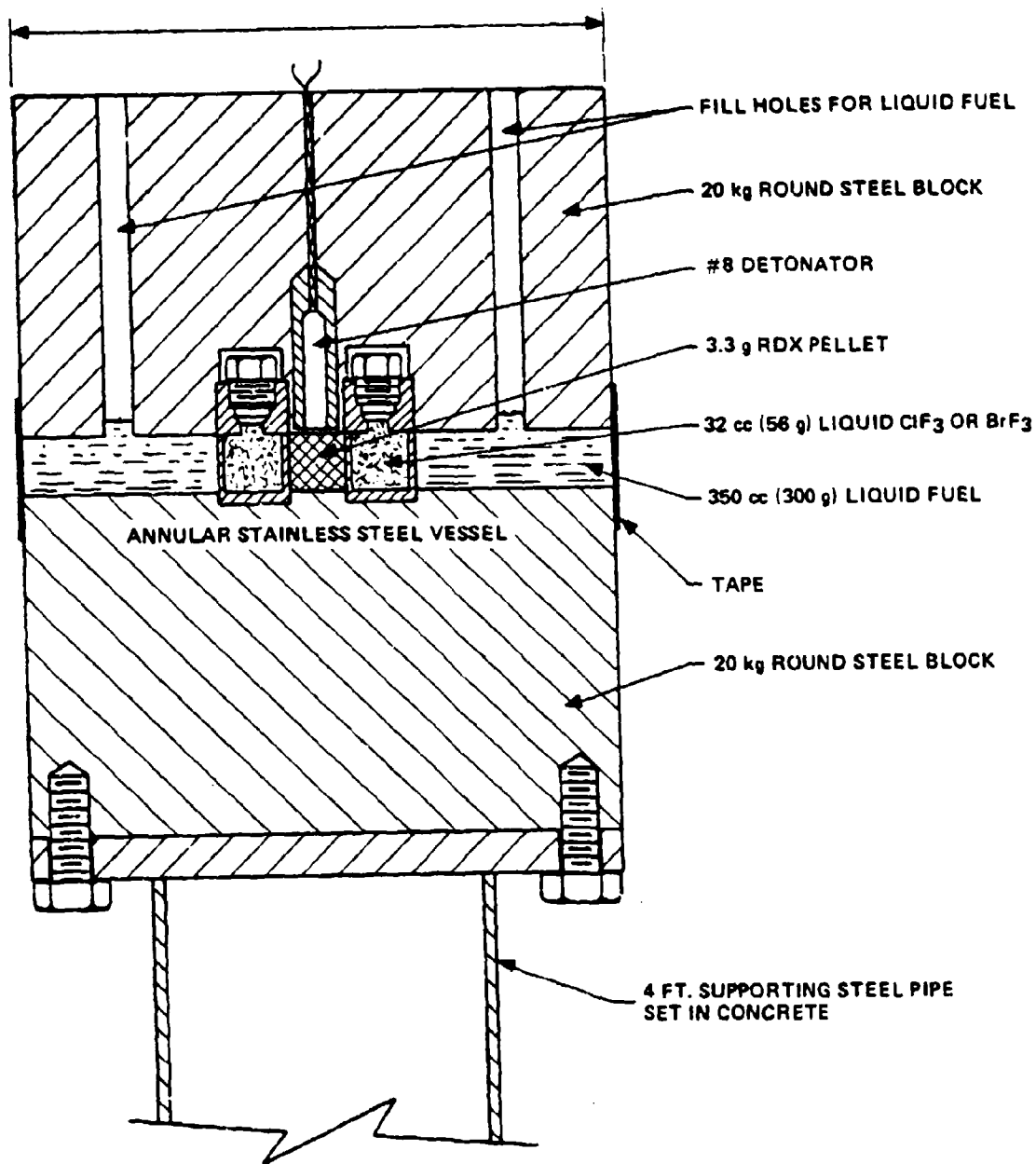


Figure 1. Schematic of Configuration for Early FAE Experiments (Side-on View).

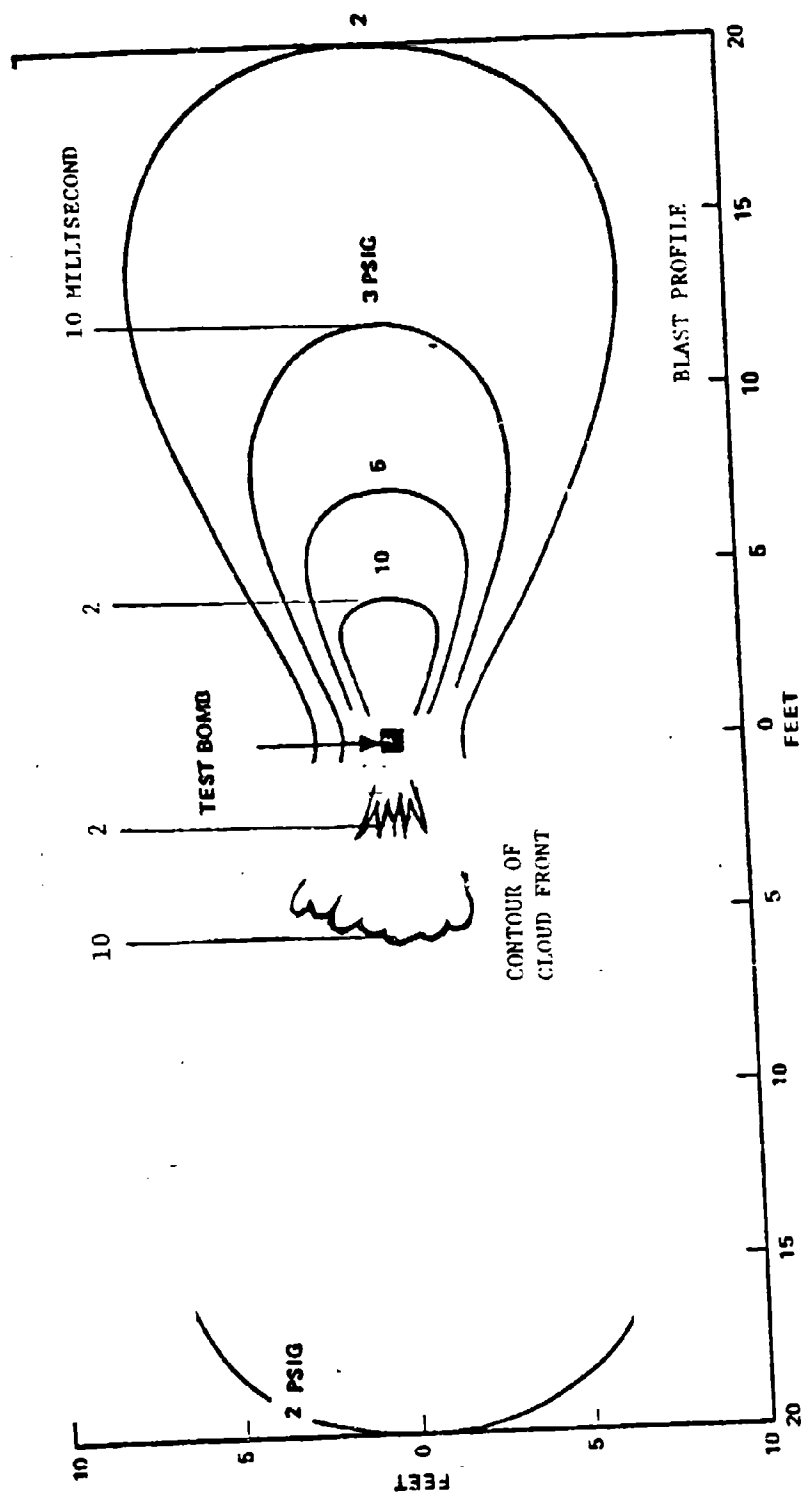


Figure 2. Approximate Cloud Contours and Blast Pressures at Various Times and Distances Obtained in the Earlier Experimental Configuration.

entrapment of air in the pockets of the serrated cloud was found to be a primary factor in blast generation. However, only a fraction of the required combustion air was entrained in this way by the cloud and the blast yield was correspondingly reduced. On this basis it was concluded that subsequent experiments should be directed toward more efficient air entrainment by promoting the entrapment of air in the cloud pockets.

3.0 WORK DONE DURING THE REPORT PERIOD

3.1 Test Concept and Experimentation

In planning the experiments it was understood that the previous small test scale (less than one pound of fuel) should be maintained, but that the central explosive charge should be substantially increased in order to enhance the serration of the cloud by the effect of Taylor instability. An additional means of serrating the cloud was suggested by the shaped-charge effect. A charge that is indented in the form of a star would combine the principles of Taylor instability and shaped charge to generate very fast jet streams of fuel and agent dispersion that would deeply penetrate into the ambient air. Agent containers of stainless steel would be placed in the recesses of the star configuration and in this way the agent would be effectively interspersed with the hydrocarbon fuel. It is understood that liquid CTF or BTF and liquid hydrocarbon are totally immiscible, but being heavier than hydrocarbons and being driven by the detonating charge, the fluorine agents are bound to be instantly interspersed with the fuel by virtue of the extreme Taylor instability of the liquid-liquid interface. The break-up of the liquids into droplets by the shock of several hundred kilobars probably occurs by a criss-cross fracture mechanism and instantly produces very small droplets, as had been noted in the previous test series when the experiment was performed in nitrogen and the fuel became dispersed in the nitrogen atmosphere as a persistent aerosol. Thus, jets of fine droplets would be formed which would entrain the air in their paths, but it was thought that this air would be only a fraction of the air that is required for combustion of the fuel, and that most of the combustion air would have to be acquired by entrainment of the air that is entrapped between the droplet streamers. It was thought that this also would be a very rapid process due to the explosive reaction within the streamers, which would drive the streamer fluid into the entrapped air. In the course of the FAE program it has been observed that with CTF,

ignition occurs approximately within 10 to 50 microseconds, whereas with BTF the ignition lag is of the order of several hundred microseconds. Thus, with CTF the streamers would explode almost immediately and engulf the entrapped air by explosion-generated turbulence, whereas with BTF there would be a period of ignition delay during which the air is entrained by the turbulence of the jet streams. One would have to determine by experiment which process is preferable with respect to blast yield.

The experimental design was based on this concept, but the concept provided no guidance with respect to quantities, dimensions and charge-shaping, which therefore had to be chosen intuitively. The former "pancake" configuration in which the test section is confined between two massive steel blocks was retained, but the test section was reduced from a 360° disk to a 120° segment, the remaining 240° being taken up by a steel cradle as shown in Figure 3. The thickness of the test section was increased from 3/4 in. to 1 in. and the circular diameter was increased from 7 in. to 8 in. The central explosive charge was increased from 4 grams to 80 grams and was given a star shape with 60° angles, as shown. About 12 cm³ of liquid CTF in a triangular stainless steel vessel was placed into each of the recesses in the charge, and the residual volume was taken up by the fuel. The CTF vessels were fitted with inlet and outlet valves which are not shown in the figure. They were passivated by flushing with CTF vapor and then charged with liquid CTF by condensing the vapor with dry ice. Care was taken to maintain a small ullage in order to limit the pressure in the vessels to the vapor pressure of CTF, which at ambient temperatures is only of the order of a few psig. The fuel was heptane in the present testing, but it may be mentioned that in the previous tests no significant difference was found in the blast performance of heptane and diesel oil. The fuel was held in place by plastic tape which covered the gap between the steel blocks.

The test assembly comprising the test section and the confining steel blocks was mounted in a horizontal position so that the blast was directed upwards, and pressure sensors were mounted on a scaffold at various locations in the plane of the 120° arc of the test section. To guard against fragment missiles, the tests were performed in a concrete shelter, about 18' wide and

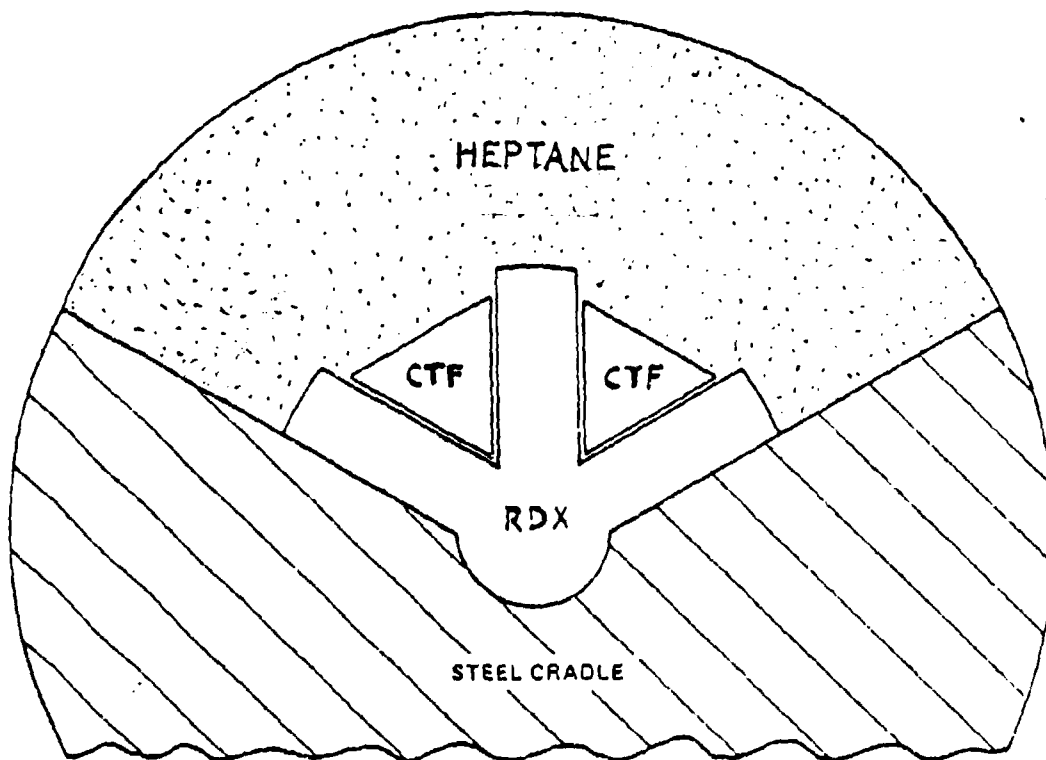


Figure 3. Schematic of Latest Configuration Which Produces a Serrated-Type of FAE Cloud and Leads to Efficient Reinforcement of Blast Wave.

10' high, that is normally used for rocket testing. High-speed motion pictures were taken with the camera placed in an oblique line of sight at a safe distance from the test. In case of a misfire -- which did not occur -- the device could be disarmed by pulling the steel blocks apart from a safe distance. The steel blocks were driven apart by the explosive charge at a velocity of about 120 ft/sec. They were stopped by sand bags and an embankment in front of the shelter.

As discussed below, the blast pattern in these experimental explosions was not understood until after the last test in the series. This made it impossible to study the difference in the performance of CTF and BTF. Hence, no experiments were made with BTF. However, the principal objective of demonstrating the viability of the new FAE concept and arriving at a model for scaling purposes was achieved.

3.2 Test Results and FAE Model

Altogether, five explosion experiments were performed, but much time was spent to track down the causes of what appeared to be severe anomalies and inconsistencies in the pressure records that were obtained from the various piezoelectric gages. In the end, these problems were resolved as follows:

1. The detonation of the explosive charge generates electric signals by a mechanism which is apparently connected with the interspersions of CTF and hydrocarbon. Although the gages are mounted in metal tubes and wired to coaxial cables, they pick up these signals as well as subsequent pressure signals through the non-conductive cover of the sensing element at the tube end. In the previous tests, these early electric signals had been weak and had been tentatively considered to be inconsequential surges in the gage circuitry incident to the initiation of the electric detonator. In the present tests the much larger explosive charge and consequently much more rapid interspersions of the liquids produced early signals ranging from very strong to weak, depending on the distance and position of the gages. Such signals had never been observed before and it was therefore necessary to positively establish their origin. Their electric nature was indicated by the simultaneous response of the gages at the various stations within a reading accuracy of ± 0.05 millisecond, and by the fact that the negative phase of the signal oscillation was frequently swinging far beyond the limit of a negative pressure phase. However, this was put in question by the failure of an attempt

to produce gage responses with electric sparks. Alternatively there was the idea, however far-fetched, that the effect might be due to a virtually simultaneous arrival of shock wave at the various stations, and that at some stations the shock might be strong enough to cause the gage to ring. It was only after the last test of the series that this thought was finally dismissed. It was learned that electric signals also occur under certain circumstances in blasting practice and that gages have recently been developed which are immune to such signals. A gage of this kind was employed in the last test and produced a pressure record without the preceding signal that had been obtained with other gages. The failure of the spark tests was accordingly attributed to an order-of-magnitude difference between the electromagnetic radiation of the sparks that had been used and the radiation incident to explosive CTF/hydrocarbon interspersion.

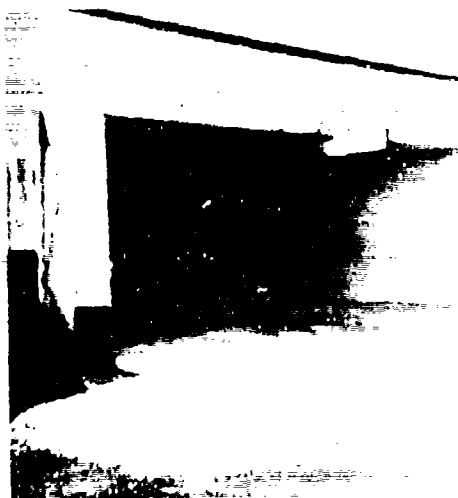
2. Explosively reacting jets of fuel and agent dispersion are in fact generated and produce a coherent shock wave as anticipated by the test concept, but the direction of the wave was misjudged in the placement of the pressure gages. The jets form a fan-shaped cloud in the plane of the test section, which is a segment of a cylindrical wafer, and the cloud expands predominantly in the lateral, viz., axial direction, generating a shock wave on each side of the fan so that two waves propagate in opposite directions more or less parallel to the axis of the test bomb. This had not been anticipated; instead, it had been thought that the cloud would predominantly expand in the radial direction, i.e., normal to the axis of the test bomb, and this misconception was not discovered until after the last test of the series. In this test the bomb had been turned to afford a camera view of the lateral expansion of the FAE cloud, and the axially propagating shock wave became visible as a transparent discontinuity. It was thus explained why a signal of the cloud expansion was received only by the gage at three feet above the bomb center, whereas the other gages received no signals other than reflected shocks from the walls of the test bay. This information confirmed the unexpected pattern of mass flow and shock generation in these experiments, which under the circumstances was more valuable than measurements of the pressure in the two shock waves.

The following is a description of the explosion experiments in the order of their performance.

In test #1 three gages were mounted above the center of the bomb at heights of 3, 6 and 8 feet, respectively, and two gages were mounted in line with the indentations of the RDX charge at 3 feet from the center. The signal-receiving end faces of the tubular gages were oriented parallel to the plane of the test wafer in order to measure the static pressure of the supposedly radially-propagating shock wave. Figure 4 shows a photograph of the set-up in the test bay and two frames of the motion picture of the exploding cloud. It is seen that there are two lobes of flame corresponding to the two indentations in the central RDX charge, but due to the attitude of the bomb and the camera, the angle of view is such that the principally axial, viz., forward and backward expansion of the cloud is obscured. It was therefore not recognized that there had been strong shocks forward and backward and that the gages as mounted were not in the path of the shocks. The most conspicuous feature of the gage records was the strong electric signal of the CTF-hydrocarbon interspersion, which was received simultaneously by all gages with intensities varying according to distance from the source; but strong shocks were registered only by the gage at three feet above the bomb center. The record of this gage is shown in Figure 5. The shock occurring at 7.3 milliseconds after the electric signal seems to have been caused by shock reflection from the rear of the bay. The earlier shock at 2 milliseconds was apparently an incident shock from an exploding jet streamer, as discussed at the end of this section.

Test #2 was a repetition of the previous test, made without an understanding of the blast pattern on the supposition that "something had gone wrong" and all gage records had been spurious. Great care was taken to check the gage circuits and each gage was tested by setting off an electric detonator in close proximity. The gages were found to be in perfect order, but the records that were obtained were similar to the records of the previous test. Thus, the answer to the problem had not been found.

The camera speed had been increased from the previous speed of one frame per millisecond to one frame per 0.2 millisecond. This gave a more detailed view of the early stage of cloud generation and confirmed that CTF generates reaction centers almost instantly in the emerging cloud.



CONCRETE SHELTER WITH
INSTRUMENT SCAFFOLD AND
TEST BOMB BETWEEN SANDBAGS



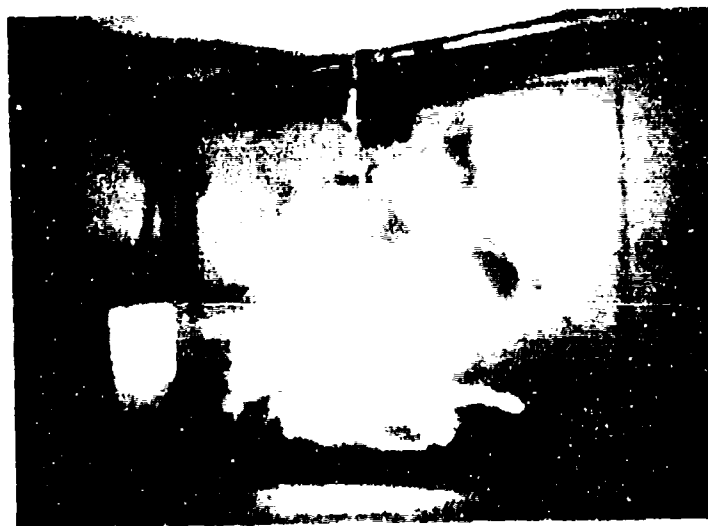
ATTITUDE OF TEST BOMB



20 FT.
SCALE



TIME AFTER
INITIATION
3 MILLISECONDS



4 MILLISECONDS

Figure 4. Exploding FAE Cloud in Test No. 1.

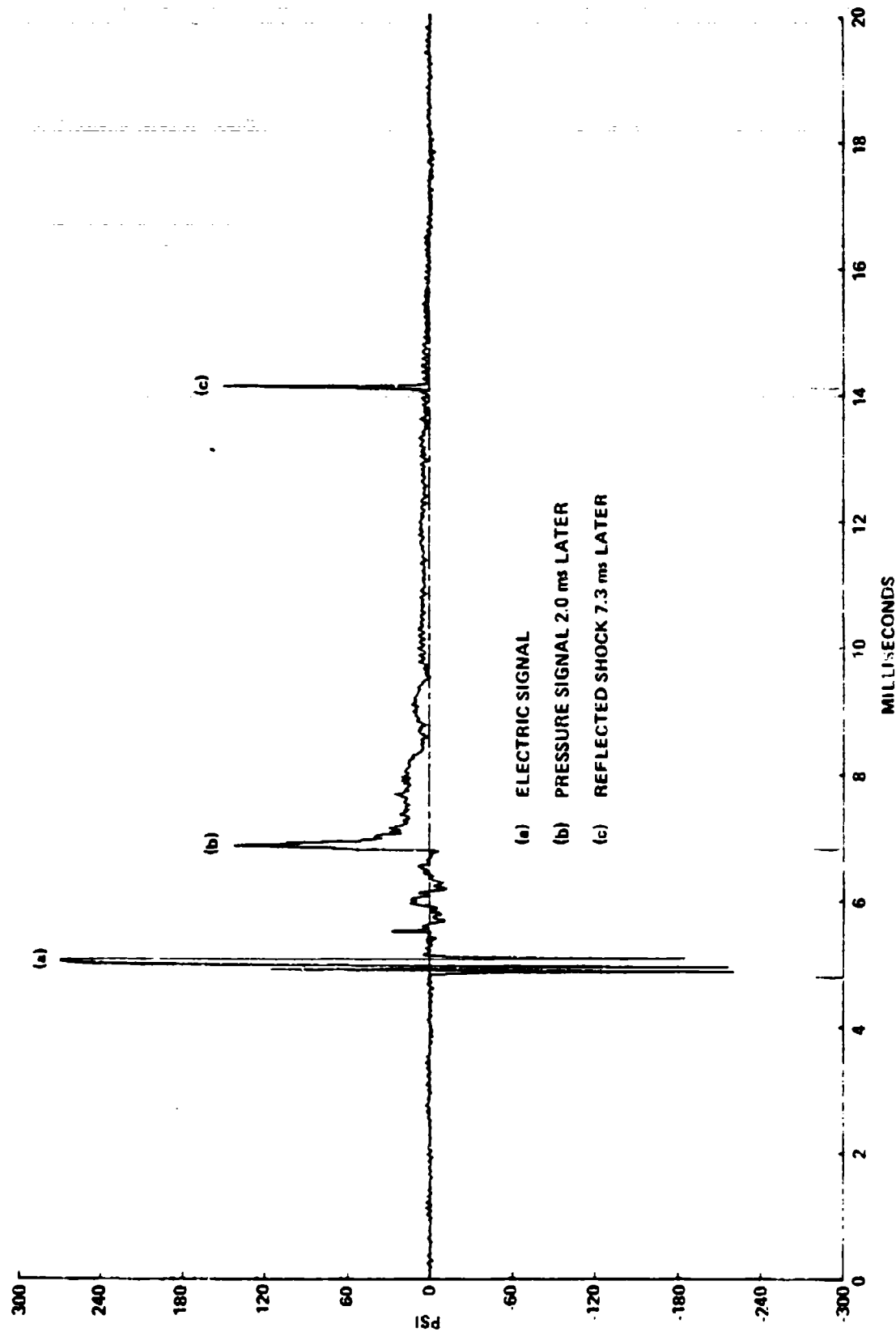


Figure 5. Test No. 1: Record of Pressure Gage at 3 FT. Above Bomb Center.

A break-through occurred in test #3, in which the CTF vessels had been omitted and the explosive charge was merely dispersing the heptane fuel. The cloud did not ignite in this test and hence there was no flame to provide illumination for high-speed photography, but effective illumination was provided by a beam of sunlight that was thrown into the test bay by a large mirror. The camera caught a good view of a fan of discrete and far-reaching jets of fuel mist as envisaged in the test concept. This is shown in Figure 6 which was obtained by projecting the first and second frames of the picture series on a screen and tracing the outline of the cloud. The first frame shows the emerging cloud at about 0.3 milliseconds after the detonation of the charge, and the second frame shows the jet structure of the cloud one millisecond later. Subsequently, the jets broaden very rapidly and the cloud becomes amorphous. The pressure gages, which had been mounted as before, gave records showing random pressure spikes of low order, i.e., a few psi as compared to the 140 - 150 psi spikes shown in Figure 5. This confirms that the shock of the detonating charge is substantially used up in the break-up and acceleration of the surrounding liquid and does not contribute significantly to the FAE blast that occurs when CTF is added. This blast is generated by the mass flow that is produced by the expansion of the exploding jets of dispersed fuel and CTF and the resulting entrainment and combustion of the entrapped air between the jets. In a cylindrical configuration the flow would necessarily be radially outward from the cylinder and produce a more or less cylindrical shock wave. This had been thought to occur in these tests; however, in the present wafer-like test configuration the flow originates from the two faces of the jet fan and generates a shock wave on each side of the fan. Thus, the principle of this novel FAE system was clearly established, but the fact that in the present tests there were two waves propagating both ways in the axial direction of the test bomb was not recognized until the end of the test series.

There were no early simultaneous signals in the gage records of test #3, which shows that these signals are not generated without CTF. This fact, in conjunction with the observed fan shape of the cloud, briefly revived the idea that the early signals in tests #1 and #2 might after all be due to shocks, being generated virtually simultaneously in the cloud fan and reaching all stations virtually simultaneously. In that case the signal strength would

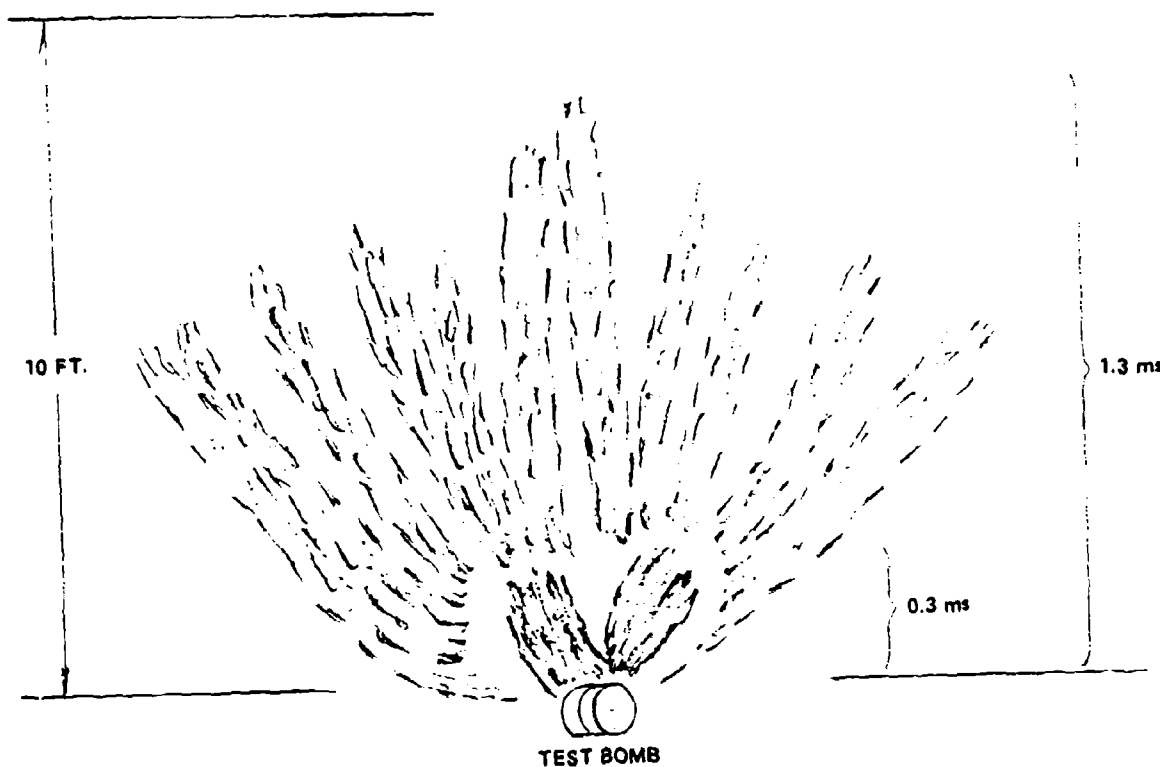


Figure 6. Fuel Dispersion without Agent (No Ignition). Size and Pattern of Cloud at 0.3 and 1.3 Millisecond. Sketch Made from Photographs.

be reduced by performing a test in a nitrogen atmosphere, which would eliminate the fuel/oxygen reaction. Accordingly, test #4 was performed in a large transparent tent that was purged with nitrogen. The result was in fact a large reduction in the strength of the early simultaneous signals, but this was offset by the photographic observation that the luminous cloud of reacting CTF and hydrocarbon did not reach the various stations simultaneously, and further, that in this test the subsequent pressure signals of reflected shocks were much larger than the early simultaneous signals. The reduced strength of the latter signals is not explained, but any remaining doubt of their electric nature was removed by test #5, in which a recently developed gage was used which is immune to electric effects and did not register the early signal.

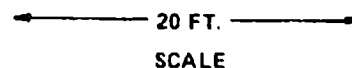
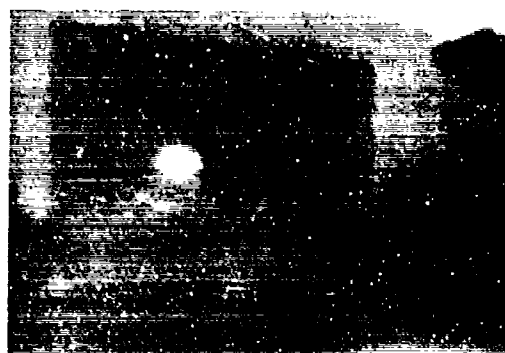
Of interest is the fact that in test #4 a bikini gage had been added to the other gages and for technical reasons was mounted well outside the plane of the test wafer. This gage was thus in the path of the axially propagating shock wave, and even though the shock was generated by the CTF/fuel reaction only and no oxygen was present, the gage was completely perforated. Gages of this type are not considered reliable, but an incident shock well in excess of 100 psi is indicated.

Test #5 finally brought the realization that the piezoelectric gages had never been in front of the expanding cloud where they would receive the signal of the coherent axial shock wave. The test bomb had been turned into the attitude shown at the top of Figure 7, and the well-rounded contour of the axially expanding cloud came into view. In the second frame of the motion picture series a Mach number >3 is inferred from the fact that between the first and the second frame the cloud has advanced over a distance of more than three feet in a millisecond. In the fourth frame the shock wave has drawn away from the cloud and becomes visible as an optical discontinuity.

By courtesy of Mr. Ben Granath, owner of Susquehanna Instruments, Inc., a gage designated as Model ST-2 was obtained which is effectively shielded against electromagnetic radiation. The torpedo-shaped gage was suspended at three feet above the bomb center and registered a pressure of 25 psi followed by reflected shocks up to 65 psi. The reflections presumably occurred at the slanting sidewalls of the test bay and are consistent with approaching primary shock waves $> \text{Mach } 3$ at intermediate distance from the wall. Pressures estimated to have been in the 10 psi range were indicated by bikini gages in the

MILLISECOND

0.3



1.3

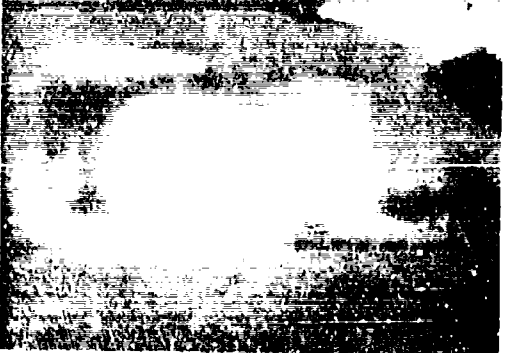


SHOCK > MACH 3

2.3



3.3



SHOCK WAVE VISIBLE
AHEAD OF CLOUD

Figure 7. Exploding FAE Cloud in Test No. 5.

plane of the test wafer at 20 feet distance, but due to a mishap no piezo-electric signals were recorded at that station.

The model of the experimental FAE system that has emerged from the described tests is largely consistent with the original test concept and is illustrated in the upper part of Figure 8. Due to the wafer-like test configuration that has been used the detonation of the explosive charge produces a sheet of jets of fuel and agent dispersion which explodes and expands axially, i.e., normal to the plane of the test wafer, and there is no significant expansion in the radial direction, i.e., normal to the axis of the test bomb. Consequently a divergent mass flow develops as shown by the flow lines on the right, and two shock waves propagate more or less parallel to the axis in opposite directions. Pressure gages mounted high above the bomb center receive no signal other than reflected shocks. As shown by gage records, this applies to gages at six feet or more above the bomb center, whereas at a height of three feet the gage registers shocks generated by the randomly developing explosion center. Such discrete centers are visible as brightly luminous spots in the first frame of the motion picture series in Figure 7. As mentioned earlier, in test #1 the sensing face of the gage was oriented parallel to the plane of the wafer. In this attitude the shock from an explosion center is substantially incident to the face, and accordingly a high pressure of 140 psi was registered. The torpedo-shaped gage in test #6 has a cylindrical sensing face which was thus only partially exposed to shock and registered a pressure of only 25 psi.

Although the dual shock waves have not been monitored by pressure gages, this is offset by the fact that the gage records show a field of no shocks above the bomb center and thus directly confirm the divergence of the mass flow that is shown in the model.

3.3 Scaling Considerations

The limitations of the test scale that are in force at the Pine Ridge facility of Atlantic Research do not permit an examination of the tests to a cylindrical configuration, but if it were done one would expect to obtain a more or less cylindrical shock wave as illustrated by the model sketch in the lower part of Figure 8. In that case the jet cloud would be an annulus around the cylinder and by explosion would expand radially as well as axially. The

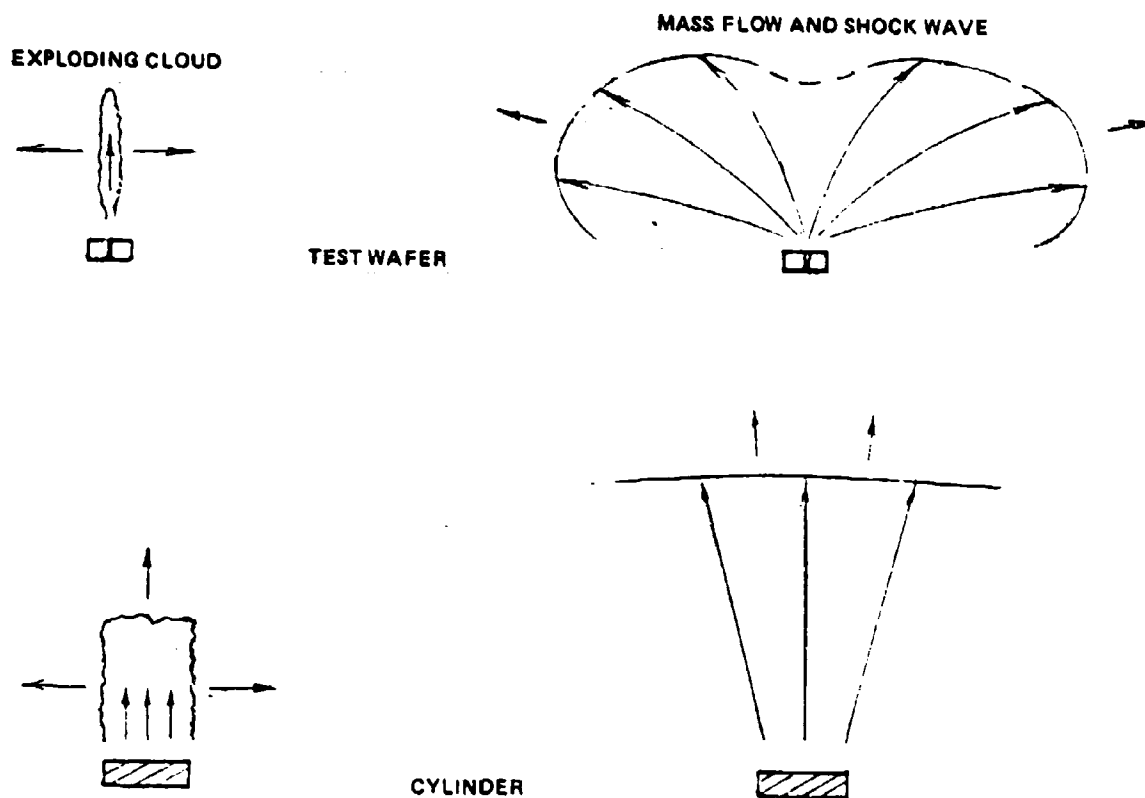


Figure 8. Models of FAE Systems.

resulting mass flow and shock wave would be much less divergent and hence the shock strength would be of a higher order than can be obtained with the present test configuration. Thus, if future small-scale experiments with test wafers confirm that pressures corresponding to shock waves of the order of Mach 3 are generated, one may expect that by axial scale-up of the system shock Mach numbers of the order of 4 - 5 are obtained. In that case the rise of temperature and pressure in the shock front would significantly accelerate the rate of combustion and increase the drive of the shock, so that a high-order detonation wave would develop and the blast performance would be similar to "second-event" initiation.

For a given length of the cylindrical FAE device one has the further options of changing the quantities of fuel, agent and explosive charge, and also the number, depth and distribution of jet-generating indentations in the charge. These options are governed by the consideration that a jet-structured cloud should develop which entraps an adequate volume of combustion air, and that the state of dispersion of fuel and agent in the jets, the agent concentration and the proximity of the jets should be adequate for high-order explosive expansion and merger of the jets to generate a strong radially-oriented mass flow. It seems that in the present test configuration these conditions have been largely met except for the axial divergence of the mass flow due to the small wafer thickness. In fact, it seems that the charge and CTF quantities that have been used could accommodate a larger quantity of fuel, to generate a larger cloud with probably no loss of shock strength. It seems also in order to increase the number of indentations in the explosive charge in order to get a more uniform cloud shape.

With respect to the state of dispersion of the liquids in the jet cloud, it has been already mentioned that in the previous tests where a much smaller quantity of explosive was used that the size of the dispersed droplets was in the range of aerosols and, hence, there is no problem of droplet size that would interfere with the explosive reaction. With respect to mixing of the jet fluid with the entrapped air, it has been pointed out that explosion centers are formed which drive the jet fluid into the entrapped air, and in this way mixing and combustion occur at the required high rate for generating the high order of mass flow for a strong shock. However, further studies of the mixing of jet fluid and entrapped air are indicated. In particular, if BTF were used in place of CTF,

there would be an ignition delay during which the jet fluid mixes with the entrapped air by turbulence, and hence it is of interest to perform experiments with BTF.

Another consideration applies to the kinetic limitation of the rate of burn-out of the fuel. In the present tests the cloud remained strongly luminous in late stages of cloud expansion, i.e., during a period of the order of 50 milliseconds, and thus a loss of shock strength due to incomplete burn-out is indicated. A measure of the utilization of the entrapped combustion air may be obtained by further experiments in a nitrogen atmosphere, which allow a comparison of the shocks that are generated by reaction of fuel with CTF and oxygen and by reaction with CTF alone. But it seems that the problem of incomplete burn-out is limited to small-scale explosion experiments. There should be no such problem in a scaled-up system in which the reaction rate is accelerated by shock compression and a detonation wave develops.

It should be possible in time to quantify the described FAE model by experiments and theory and to arrive at predictive scaling relations.

4.0 FUTURE WORK

The foregoing points to the direction that should be followed in further experimentation. The basic small test configuration cannot be used to demonstrate the transition of the coherent shock wave to detonation which is expected to occur in a cylindrically scaled-up system; however, it retains its usefulness for other purposes. Thus, it is proposed to perform further experiments of this type along the following lines:

1. The effect of the ratios of dispersing charge to agent and fuel will be defined in experiments in which the relative quantities of charge and fuel are varied.
2. Shaped-charge dispersal angle will be varied with the objective of obtaining a more uniform jet structure in the initial phase of FAE cloud dispersion.
3. The agent will be changed to BTF in experiments designed to investigate the effect of the ignition delay and the slower agent/fuel reaction on the blast generation.
4. The pressure gages will be placed in the path of one of the two axially propagating shock waves, and they will include an array of crystal

transducers, strain gages and bikini gages using techniques that are known to provide good diagnostics. High-speed motion photography will continue to be used with emphasis on observing the axial cloud expansion.

5. The blast performance of a CTF-initiated FAE cloud in a nitrogen atmosphere will be determined, if feasible, within the fiscal constraints of the program, in order to obtain a measure of the relative contributions of the fuel/CTF and fuel/O₂ reactions to the blast. Furthermore, if feasible, an experiment in an oxygen atmosphere might be performed with the view of demonstrating the transition of the shock wave to detonation, which in an oxygen atmosphere may be expected to occur even at the low Mach numbers in these small-scale experiments.

The accumulated test results in conjunction with fluid-dynamic and reaction-kinetic theory should make it possible to approach the problem of quantifying the model of a chemically initiated FAE cloud that has emerged from the previous work, with a view of obtaining predictive scaling relations.